CHITINOZOA OF THE SILURIAN–DEVONIAN BOUNDARY SECTIONS IN PODOLIA, UKRAINE

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ABSTRACT. The Upper Silurian and Lower Devonian beds along the Dnestr River and its tributaries form one of the sections discussed as a possible international Global Stratigraphic Stratotype and Point (GSSP) for the Silurian–Devonian boundary. On the basis of the co-occurrence of a graptolite (*Monograptus uniformis angustidens*) and a conodont (*Icriodus woschmidti*) this boundary was drawn at the base of the Tajna Formation. However, chitinozoans from these strata are typical of Přídolí chitinozoan assemblages, and include the index species, *Urnochitina urna*, and other taxa, e.g. *Calpichitina annulata*, *Linochitina klonkensis*, in the lower part of the Tajna Formation. Early Lochkovian chitinozoans, especially the index species *Eisenackitina bohemica* and associated taxa, e.g. *Margachitina catenaria*, *Pterochitina megavelata*, *Calpichitina velata*, *Cingulochitina ervensis*, are present in the upper part of the Tajna Formation. The Silurian–Devonian boundary should therefore be drawn in the middle part of the Tajna formation. Neither late Lochkovian nor early Pragian chitinozoan species have been recorded in the investigated material. The differences noted in the respective ranges of the chitinozoan and graptolite index species in Podolia and Bohemia, suggest that the section containing the stratotype for the base of the Devonian in Bohemia may be less complete than the sequence exposed in Podolia. The Přídolí and Lochkovian chitinozoan assemblages from Podolia show striking similarities to those from south-east Poland, Bohemia and from some northern Gondwana localities. A new species, *Angochitina tsegelnjuki* sp. nov., is described.

PIONEERING work on the Lower Palaeozoic of Podolia during the nineteenth century attracted the attention of many palaeontologists and stratigraphers. The first biostratigraphical investigation was carried out by Kozłowski (1929), who worked on upper Silurian and lower Devonian brachiopod faunas. The Silurian was further subdivided by Nikiforova in a series of papers (e.g. Nikiforova 1948, 1954). More recent contributions are those of Nikiforova and Predtechenskij (1968), Tsegelnjuk *et al.* (1983) and Koren' *et al.* (1989). The Upper Silurian and Lower Devonian exposures along the Dnestr River were investigated in detail (Nikiforova and Predtechenskij 1968; Nikiforova 1977) as a possible international stratotype for the Silurian–Devonian boundary. The uppermost Silurian (Skala 'horizon') was also one of the candidates for the fourth series of the Silurian (Tsegelnjuk *et al.* 1983; Abushik *et al.* 1985). Information about chitinozoan faunas from Podolia is available from four papers. The Ordovician (Ashgill) and early Silurian faunas were briefly discussed by Laufeld (1971); Obut (1973) illustrated chitinozoans from Silurian and Lower Devonian beds; and Silurian chitinozoans were described or listed by Tsegelnjuk (1982) and Tsegelnjuk *et al.* (1983). Other palynomorphs, including Silurian acritarchs (Kirjanov 1978) and a few early Devonian miospores (Arkhangelskaya 1980) have also been reported from the Dnestr River area.

Podolia was a part of Baltica during the Early Palaeozoic (e.g. see Paris and Robardet 1990) and the same chitinozoan faunas could therefore be expected to be present in Podolia and Baltoscandia. This is obvious from Laufeld's paper, but the precise provenance of the chitinozoan faunas described by Obut and Tsegelnjuk is not clear. We therefore found it necessary to review the Late Silurian and Early Devonian chitinozoans from Podolia, and to compare them with contemporary faunas from nearby south-east Poland (Wrona 1980), and to the faunas of the Upper Silurian and Lower Devonian boundary stratotypes in Bohemia (Paris 1981; Paris *et al.* 1981; Paris and Kříž 1984; Chlupáč *et al.* 1985; Kříž *et al.* 1986).

The samples were collected by Sven Laufeld during the Third International Symposium on the Silurian–Devonian boundary excursion to Podolia in 1968.

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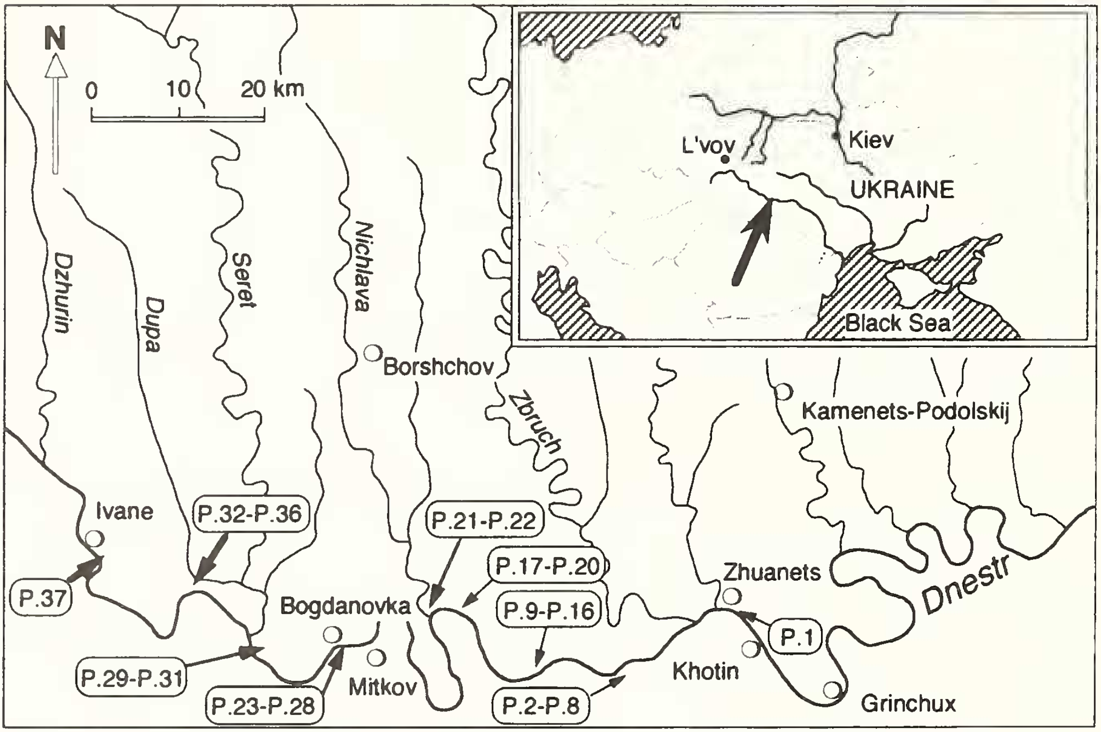
BRIEF OUTLINE OF THE UPPER SILURIAN–LOWER DEVONIAN STRATIGRAPHY OF PODOLIA

The Dnestr Basin of Podolia was occupied by a shallow epicontinental sea that existed in the south-western part of the Russian Platform during most of the Silurian and early Devonian. Lower Cambrian to Lower Devonian beds crop out along the Dnestr River and its northern tributaries from Molodovo to Ustechko villages, a distance of about 100 km (Text-fig. 1). In general the dip



TEXT-FIG. 1. Schematic location map of the sampled localities along the Dnestr River, Podolia, Ukraine. Adapted from Nikiforova and Predtechenskij (1968) and Koren' *et al.* (1989).

is 1–2° towards the west-south-west, but it may locally reach 5–6°. The stratigraphical division of the Silurian and Devonian is based on lithology and to some extent on facies reconstructions. The lithologies and the fossil content of the different formations and members have been described in several papers (for references see above). The descriptions below are based mainly on the results published by Nikiforova and Predtechenskij (1968).

Skala Group

The Skala Group (= Skala Horizon) contains, according to Nikiforova and Predtechenskij (1968), three formations (= beds in Russian literature), i.e. in ascending order, the Isakovtsy, Rashkov and Dzwinogorod formations. Later, Tsegelnjuk *et al.* (1983) transferred the Isakovtsy Formation to the Malinovtsy Group.

Koren' *et al.* (1989) also included the lowermost part of the Rashkov Formation (= Prigorodok Formation) in the Malinovtsy Group. The Skala Group is well exposed along the Dnestr, Zbruch and Zhvanchik rivers. Its lithology is mainly limestone, which alternates with dolomites, dolomitic marls, argillites and metabentonite layers. The total thickness of the Skala Group is over 151 m if the Isakovtsy Formation is included (Nikiforova and Predtechenskij 1968) or up to 136 m if one adopts the definition given by Koren' *et al.* (1989).

Isakovtsy Formation. The total thickness of the Isakovtsy Formation ranges from 32–34 m (Nikiforova and Predtechenskij 1968), 5–6 m (Tsegelnjuk *et al.* 1983) or 6–9 m (Koren' *et al.* 1989). In the basal 2–4·5 m massive dolomites occur within thin layers of dolomitic marls and bentonites; higher up, dolomitic marls with bentonites dominate. Desiccation fissures and ripple marks are common in these inner shelf to shoal or lagoon deposits (see Koren' *et al.* 1989, fig. 106). The best exposures are on the left side of Dnestr River and at Okopy village. The fauna consists mainly of brachiopods and ostracodes. The latter may form limestone coquinas. Trilobites and cystoids are scarce, whilst algae are common in the dolomites. The age is generally considered to be upper Ludlow (Koren' *et al.* 1989).

Rashkov Formation. According to Nikiforova and Predtechenskij (1968) the thickness of the Rashkov Formation is *c.* 98 m (a thickness of 170–250 m is given by Tsegelnjuk *et al.* 1983 and of 94–106 m by Koren' *et al.* 1989). The lithologies are nodular dolomite rich in stromatoporoids, bituminous limestone, tuffitic sandstone and bentonite. Desiccation fissures occur in these inner shelf to shallow open shelf deposits (see Koren' *et al.* 1989, fig. 106). A complete section is present on the left bank of the Dnestr River, near Okopy village. The fossil fauna is dominated by stromatoporoids, corals and ostracodes. These may locally be rock-forming. Other important groups are bivalves, nautiloids, bryozoans, brachiopods, trilobites and crinoids. Plant remains are also common. The lower part of the formation has been transferred to the Prigoroduk Formation by some authors (Tsegelnjuk *et al.* 1983; Koren' *et al.* 1989). Age assignments of the Rashkov Formation vary from upper Ludlow (Nikiforova and Predtechenskij 1968; Tsegelnjuk *et al.* 1983) to uppermost Ludlow–lower Přídolí (Koren' *et al.* 1989).

Dzwinogorod Formation. The estimated thickness of the Dzwinogorod Formation is *c.* 19 m according to Nikiforova and Predtechenskij (1968), 29–31 m (Tsegelnjuk *et al.* 1983) or up to 30 m (Koren' *et al.* 1989). The formation consists of grey–green marls with limestone nodules. Bentonites are present in these shallow open shelf to outer shelf (upper part of the formation) deposits (see Koren' *et al.* 1989, fig. 106). Good exposures occur at the Dzwinogorod and Volkovtsy villages. The shelly fauna is rich in stromatoporoids, corals, bivalves, nautiloids, bryozoans, brachiopods, ostracodes, trilobites and crinoids. Plant remains and conodonts have also been described from the formation. The age is considered to be uppermost Ludlow–lower Přídolí by Nikiforova and Predtechenskij (1968), and upper Přídolí by Tsegelnjuk *et al.* (1983) and Koren' *et al.* (1989).

Borshchov Group

The Borshchov Group (= Borshchov Horizon) was subdivided into three formations (= beds in the Russian literature) by Nikiforova and Predtechenskij (1968); in ascending order these are the Tajna, Mitkov and the Bogdanovka formations. The group is the thickest (*c.* 253 m) and most widespread in Podolia. The lithology is characterized by fossiliferous grey argillites, marls and limestones. The type section is at Nichlava River near Borshchov village. A complete section occurs along the Dnestr between Volkovtsy and Zazulintsy villages. The Silurian–Devonian boundary is currently correlated with the base of the Borshchov Group (Nikiforova 1977).

Tajna Formation. Nikiforova and Predtechenskij (1968) estimated the thickness of the Tajna Formation to be *c.* 57 m. The lithology consists of rhythmically intermittent marly argillite members, with lenses of limestone followed by limestone and greenish-grey marls. The sequence finishes with dark grey limestone and intercalated argillites. The formation is exposed in two areas at Dnestr and about 80 km north, at Tajna River where the type section is situated. The fauna is rich in corals, bivalves, nautiloids, bryozoans, brachiopods, trilobites and crinoids; graptolites and conodonts have also been described from the formation. The age is generally believed to be lower Lochkovian.

Mitkov Formation. The Mitkov Formation is estimated to be *c.* 126 m thick (Nikiforova and Predtechenskij 1968). The lithology is grey calcareous argillite or marly shale with bun-shaped limestone concretions. The Mitkov Formation crops out along the Dnestr River from the city of Melnitsa-Podolskaya to Bogdanovka village and along the Nichlava River. Brachiopods are common and sometimes form coquinas. Other elements of the fauna include corals, bivalves, nautiloids, bryozoans, trilobites, ostracodes, crinoids, graptolites and fish remains; plant remains and conodonts have also been described. The age is considered to be lower Lochkovian.

Bogdanovka Formation. Nikiforova and Predtechenskij (1968) determined the thickness of the Bogdanovka Formation to be *c.* 69 m. The lithology is mainly thin-bedded limestone intercalated with argillaceous marls. Brachiopods, tentaculitids and bivalves are numerous and form coquina limestones. Other common shelly fossil groups are corals and nautiloids; conodonts have also been described. Exposures are present along the Dnestr for a short distance between the Bogdanovka and Zazulintsy villages. The upper part can also be observed at Bilche Zolotoe village on the Seret River. The age of the formation is considered to be lower Lochkovian.

Chortkov Group

According to Nikiforova and Predtechenskij (1968) the total thickness of the Chortkov Group is *c.* 135 m. The group is characterized by thin beds of alternating dark grey limestone and greenish-grey argillite. Ostracodes, bivalves and tentaculitids are common and form coquinas. Other shelly fossil groups represented are bryozoans, orthocones, brachiopods and corals. Fish remains and conodonts are also common. The Chortkov Group crops out extensively along the Dnestr, the Seret and the Dupa rivers. The type section is at Seret River, north of Zvinyach city and the age is believed to be lower Lochkovian.

Ivane Group

The Ivane Group, with a total thickness of *c.* 126 m (Nikiforova and Predtechenskij 1968), can be divided into four lithological units. A lower unit (about 47 m thick) consists of grey argillites alternating with red siltstones and limestone concretions. This is overlain by a unit, *c.* 42 m thick, containing grey siltstones alternating with limestones. The third unit (*c.* 22 m thick) is characterized by bioturbated grey to yellowish-green siltstone, and the uppermost unit (*c.* 15 m thick) consists of red siltstone and limestone alternating with grey, bioturbated siltstone. The Ivane Group crops out along the Dnestr River from Dobrovlyany to Ustechko villages, and along the Seret, Belaya and Perejma rivers. The type section is located near the Ivane Zolotoe village. Except for the ostracodes, the fossil faunas are similar to those of the underlying Chortkov Group. The faunas are dominated by corals, bivalves, brachiopods, nautiloids (locally forming a coquina), tentaculitids, crinoids and fish remains. The age is believed to be upper Lochkovian.

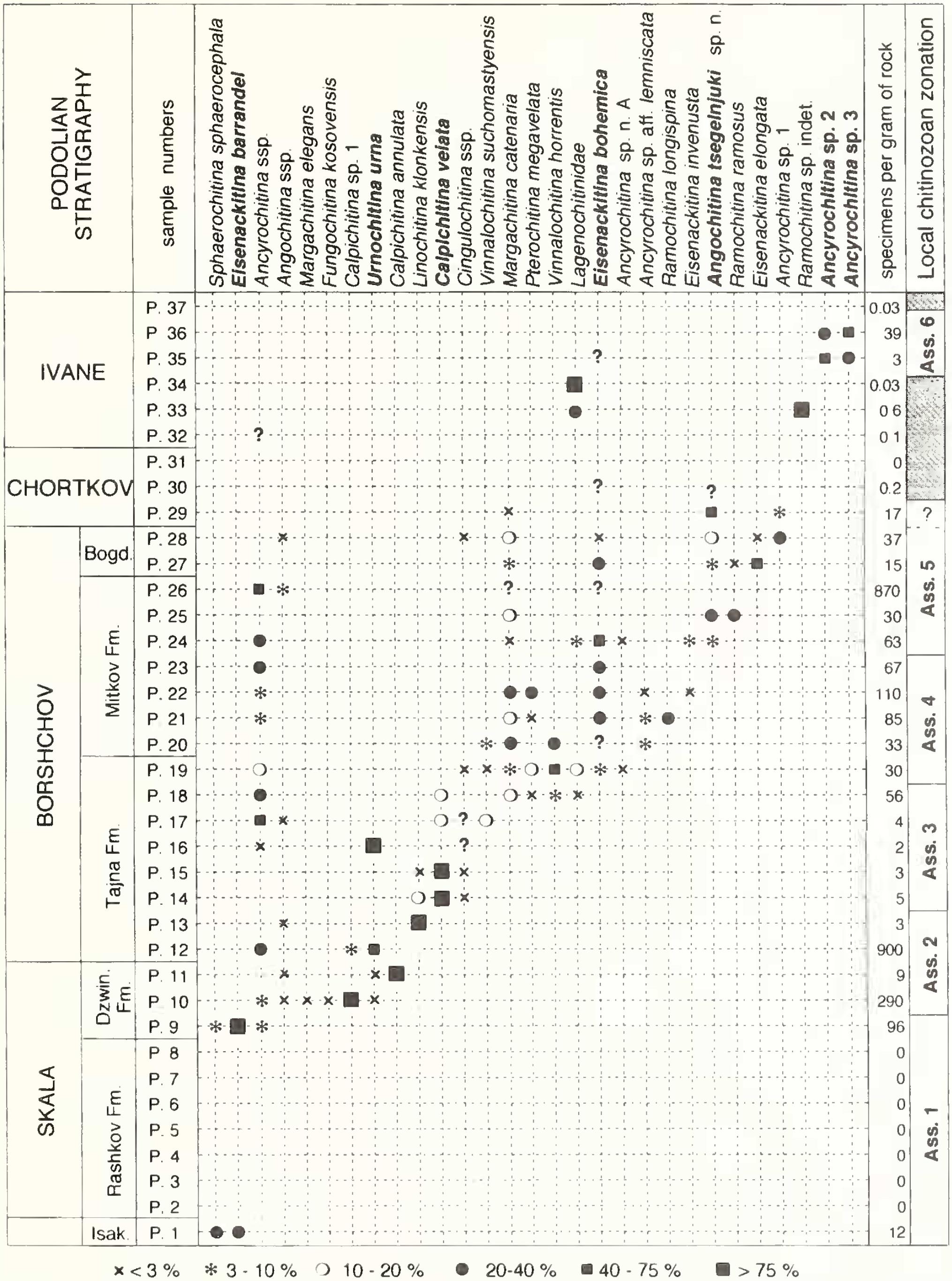
Dnestr Supergroup

The total thickness of the Dnestr Supergroup is estimated as *c.* 350 m (Nikiforova and Predtechenskij 1968). The lithology is exclusively continental red terrigenous sandstones, siltstones and mudstones. Desiccation fissures and ripple marks are common. The Supergroup crops out along the Dnestr River, from Zaleshchiki city to Ustechko village, and along the Dupa, Dzhurin and other rivers. Numerous fish remains are present in the basal part, and based on these, the age is at the Lochkovian–Pragian transition (Nikiforova and Predtechenskij 1968; Karatajute-Talimaa 1978).

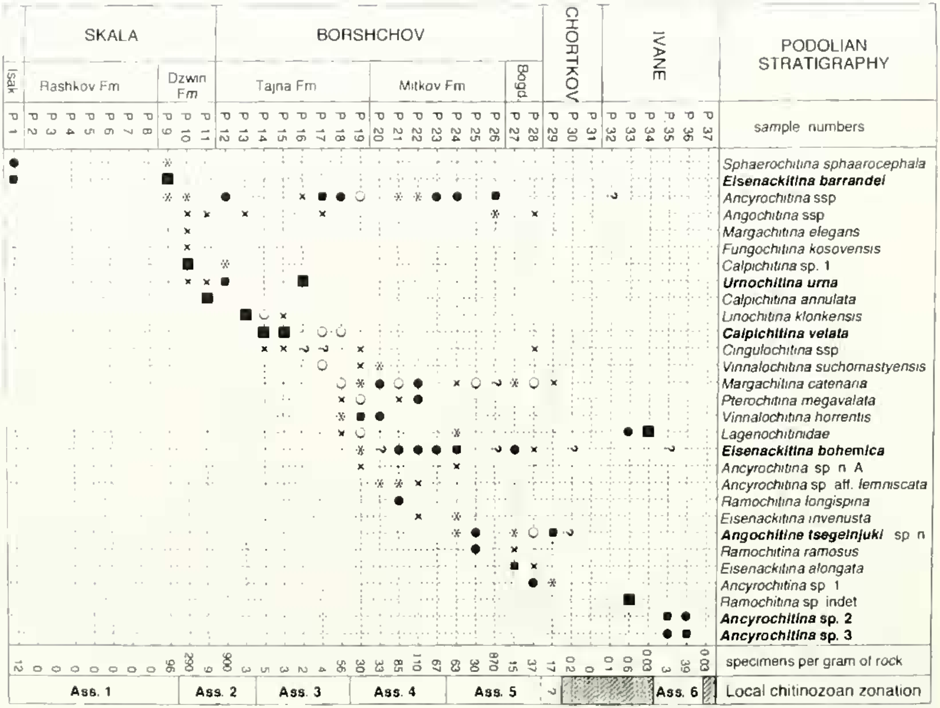
METHODS, AND LOCALITIES STUDIED

Thirty-seven samples from nine localities exposing a marine sequence of Upper Silurian–Lower Devonian age have been investigated for chitinozoans. Standard methods for laboratory and electron microscope studies (Paris 1981) were used. The locality numbers referred to are those of Nikiforova and Predtechenskij (1968). It should be noted that our sparsely distributed samples do not allow a detailed study of the actual sequence; such a study would require hundreds of closely collected samples.

Near Zhwanetz village (locality 83, river-bank exposure on the left side of the Dnestr about 500 m above the bridge at Zhwanetz village), approximately 12 m of the Grinchuk Formation of the Malinovtsy Group is overlain by the basal 12 m of the Isakovtsy Formation. Sample P. 1 was taken at the base of the Isakovtsy Formation.



TEXT-FIG. 2. Distribution, abundance and local biozonation of the chitinozoans in the Upper Silurian and Lower Devonian sequences of the Dnestr valley, Podolia, Ukraine. Index taxa of the local chitinozoan zonation are in bold. Local stratigraphical terminology from Nikiforova and Predtechenskij (1968) and Koren' *et al.* (1989).



× < 3 % ※ 3 - 10 % ○ 10 - 20 % ● 20-40 % ■ 40 - 75 % ■ > 75 %

FIG. 2. Distribution, abundance and local biozonation of the chitinozoans in the Upper Silurian and Lower Devonian sequences of the Dnestr valley, Podolia, Ukraine. Index taxa of the local chitinozoan zonation are in bold. Local stratigraphical terminology from Nikiforova and Predtechenskij (1968) and Koren' *et al.* (1989).

At Trubchin village (locality 38, exposure on the left side of the Dnestr about 400 m below Trubchin village), typical beds of the middle part of the Rashkov Formation are exposed. Seven samples (P.2 to P.8) were collected in the lower and middle part of the section (Text-fig. 3). All were barren (Text-fig. 2).

At Volkovtsy village (locality 64, exposure at a gully near a church at Volkovtsy village), at the left side and at the base of the gully, nearly 7 m of the upper Dzwinogorod Formation are exposed; three samples were collected from this part (P.9 to P.11) These beds are overlain by more than 20 m of the Tajna Formation. Four samples (P.12 to P.15) were collected in the basal part of the Tajna Formation, and one sample (P.16) from higher up in the section (Text-fig. 3).

Close to Chudkovtsy village (locality 48, exposure at the left side of the Dnestr River about 500 m above Chudkovtsy village; Text-fig. 1), the upper Tajna Formation is exposed in the lower part of the section and about 20 m of the Mitkov Formation is visible above this. The Devonian beds are overlain here by Cenomanian limestones. Three samples (P.17, P.18 and P.19) were collected from the Tajna Formation, at the base and in the top of the exposed sequence, and one sample (P.20) in the basal part of the overlying Mitkov Formation (Text-fig. 3).

At Mikhalkov village (locality 92, exposure on the left side of the Nichlava River opposite the mill at Ustje village; Text-fig. 1), over 40 m of the middle Mitkov Formation are exposed. Samples were taken at the base (P.21) and the middle part (P.22) of the section (Text-fig. 3).

Near Bogdanovka village (locality 56, exposure in a creek on the left side of Dnestr River, about 1 km below the Bogdanovka village; Text-fig. 1), the upper part of the Mitkov Formation and the lower part of the overlying Bogdanovka Formation are exposed. Four samples (P.23 to P.26) were collected in the Mitkov Formation, and two samples (P.27 and P.28) in the lower Bogdanovka Formation (Text-fig. 3).

Near Gorodok village (locality 81, road-cut on the left side of the Seret River along the road between Kulakovtsy and Gorodok villages), the middle part of the Chortkov Group is exposed. Three samples (P.29–P.31) were collected in the lower segment of this exposure (Text-fig. 3).

Close to Dosrovlyany village (locality 73, exposure on the left side of the Dnestr about 500 m below Dobrovlyany village), the lower part of the Ivane Group is present. Five samples (P.32 to P.36) were collected from the middle and upper part of the section (Text-fig. 3).

At Ivane-Zolotoe village (locality 76, exposure on the left side of the Dnestr about 500 m below Ivane-Zolotoe village), *c.* 36 m of the upper Ivane Group and nearly 50 m of the lower Dnestr Supergroup crop out in rain-rills of a steep slope in the valley. One sample (P.37) was collected at the top of the Ivane Group (Text-fig. 3).

EXPLANATION OF PLATE 1

Chitinozoans from Tajna and Mitkov formations, Podolia, Ukraine.

Figs 1, 6. *Calpichitina annulata* (Paris and Laufeld, *in* Paris *et al.*, 1981). 1, P.11, IGR 58706 (O.40/4); oblique apertural view; ×400. 2, P.11, IGR 58706 (Q.43); detail of the operculum with turned-up borders; the circular perforation is due to parasite boring; ×750.

Figs 2–3, 8. *Vinnalochitina suchomastiensis* (Paris and Laufeld, *in* Paris *et al.*, 1981). 2, P.17, IGR 58717 (M.40); lateral view of a specimen in full relief; ×400. 3, P.20, IGR 58723 (P.39/4); lateral view of a partially flattened specimen; ×400. 8, P.20, IGR 58723 (L.40/3); anteapertural oblique view showing the scar, and the spiny ornamentation fading away toward the apex; ×400.

Fig. 4. *Cingulochitina wronai* Paris and Kříž, 1984; P.14, IGR 58712 (Q.39); isolated vesicle with a very short carina; ×400.

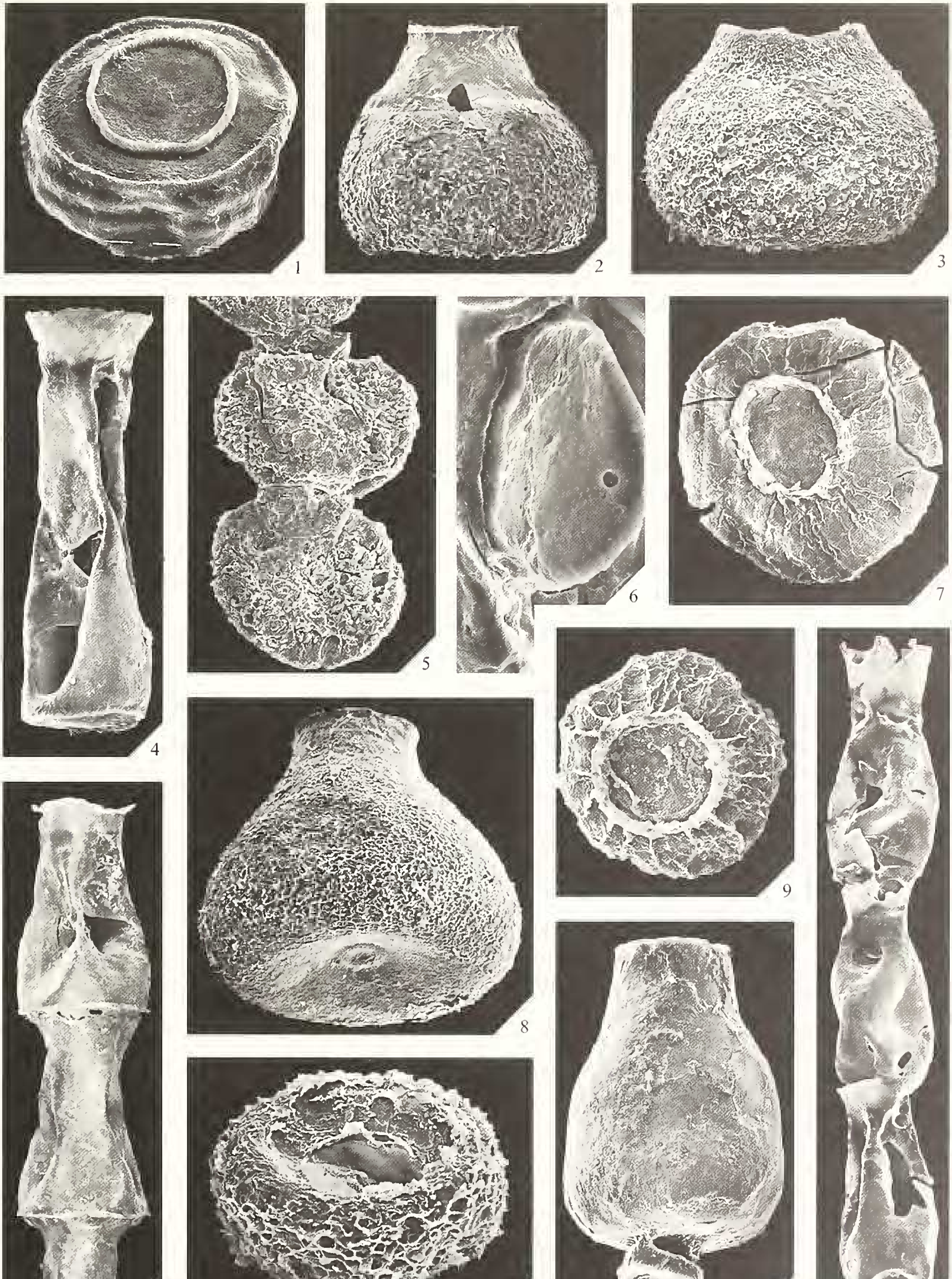
Figs 5, 11. *Vinnalochitina*? *horrentis* (Jaglin, 1985). 5, P.19, IGR 58721 (U.43/3); chain of three flattened vesicles; ×400. 11, P.20, IGR 58723 (P.40/4); apertural oblique view of an isolated specimen showing peculiar ornamentation; ×500.

Figs 7, 9. *Calpichitina velata* (Wrona, 1980). P.14, IGR 58712. 7, (R.39); apertural view of a flattened vesicle; ×400. 9, (O.36); apertural view of a specimen with well-developed outer-layer foldings; ×400.

Fig. 10. *Cingulochitina* ex. gr. *ervensis* (Paris, 1979); P.19, IGR 58721 (N.41/4); the partly collapsed flanks slightly modify the outline of these specimens; ×350.

Fig. 12. *Urnochitina urna* (Eisenack, 1934); P.12, IGR 58708 (N.41/3); note the operculum still fixed to the succeeding vesicle; ×300.

Fig. 13. *Linochitina klonkensis* (Paris and Laufeld, *in* Paris *et al.*, 1981); P.13, IGR 58710 (P.38); note the fragments of collarette remaining attached to the margin of the upper vesicle and simulating a carina; ×300.



PARIS and GRAHN, Podolian chitinozoans

CHITINOZOAN BIOSTRATIGRAPHY AND CHRONOSTRATIGRAPHY

The abundance of chitinozoans in the samples is highly variable (Text-fig. 2) and ranges from 0·03 specimens per gramme of rock (e.g. sample P. 34) up to 900 specimens per gram of rock (e.g. samples P. 12 and P. 26). The distribution and the abundance of these organic microfossils seem to be influenced by both the lithology and the environment. The lagoonal to inner shelf deposits of the Rashkov Formation are virtually barren while the outer shelf deposits (e.g. dark bituminous limestones of the Tajna or Mitkov formations) yield rich and highly diversified chitinozoan assemblages (Text-fig. 2). The reddish lithologies of the Ivane Group contain few chitinozoans but abundant organic tubes (Pl. 2, figs 4, 7–9) reminiscent of some of the terrestrial plant microfossils reported by Wellman and Richardson (1993) from the Silurian of Scotland.

Local chitinozoan biozonation (Text-fig. 2)

Six chitinozoan assemblages, corresponding to interval biozones between the first occurrence of two successive index taxa, have been identified. The term 'assemblage' is used instead of the more formal 'biozone' because the sampling is too sparse to document precisely the actual range of the recorded taxa. Most of the index species have been selected because they allow correlation with the Upper Silurian and Lower Devonian international stratotypes defined in Bohemia.

Assemblage 1. This corresponds to the total range of *Eisenackitina barrandei* in the investigated material. This index species is only recorded in the lower part of the Isakovtsy Formation (poorly preserved individuals in sample P. 1) and in the upper middle part of the Dzwinogorod Formation (sample P. 9; 80 per cent. of the recovered chitinozoans); the analysed samples from the Rashkov Formation were barren. The associated species are *Sphaerochitina sphaerocephala* (35 per cent. of the population recorded in sample P. 1), *Cingulochitina* sp. indet., a few specimens of *Ancyrochitina* sp. aff. *primitiva* and *Eisenackitina*, e.g. *E. intermedia*.

Assemblage 2. This assemblage commences with the first occurrence of *Urnochitina urna* in sample P. 10 (less than 3 per cent. of the population). This material was collected a few tens of millimetres below the top of the

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EXPLANATION OF PLATE 2

Early Lochkovian chitinozoans from the upper part of the Tajna Formation (figs 6, 10a–b) and from the lower part of the Mitkov Formation (figs 1–3, 5 and 12) of Podolia, Ukraine. A few organic tubes from the Lower Devonian of Podolia are also illustrated.

Fig. 1. *Ramochitina* sp. aff. *jouannensis* (Paris, 1976); P. 21, IGR 58727, (P. 41/3); full relief specimen in lateral view; ×350.

Figs 2–3. *Ramochitina longispina* (Wrona, 1980); P. 21, IGR 58727. 2, (S. 39/4); ×350. 3, (S. 42/3); ×350.

Fig. 4. Organic 'tube' with a vermiculate outer surface, P. 32, IGR 58745, (Q. 40/2); lower part of the Ivane Group; ×600.

Fig. 5. *Eisenackitina invenusta* Wrona, 1980; P. 22, IGR 58728, (N. 38/4); specimen with partly collapsed flanks; ×300.

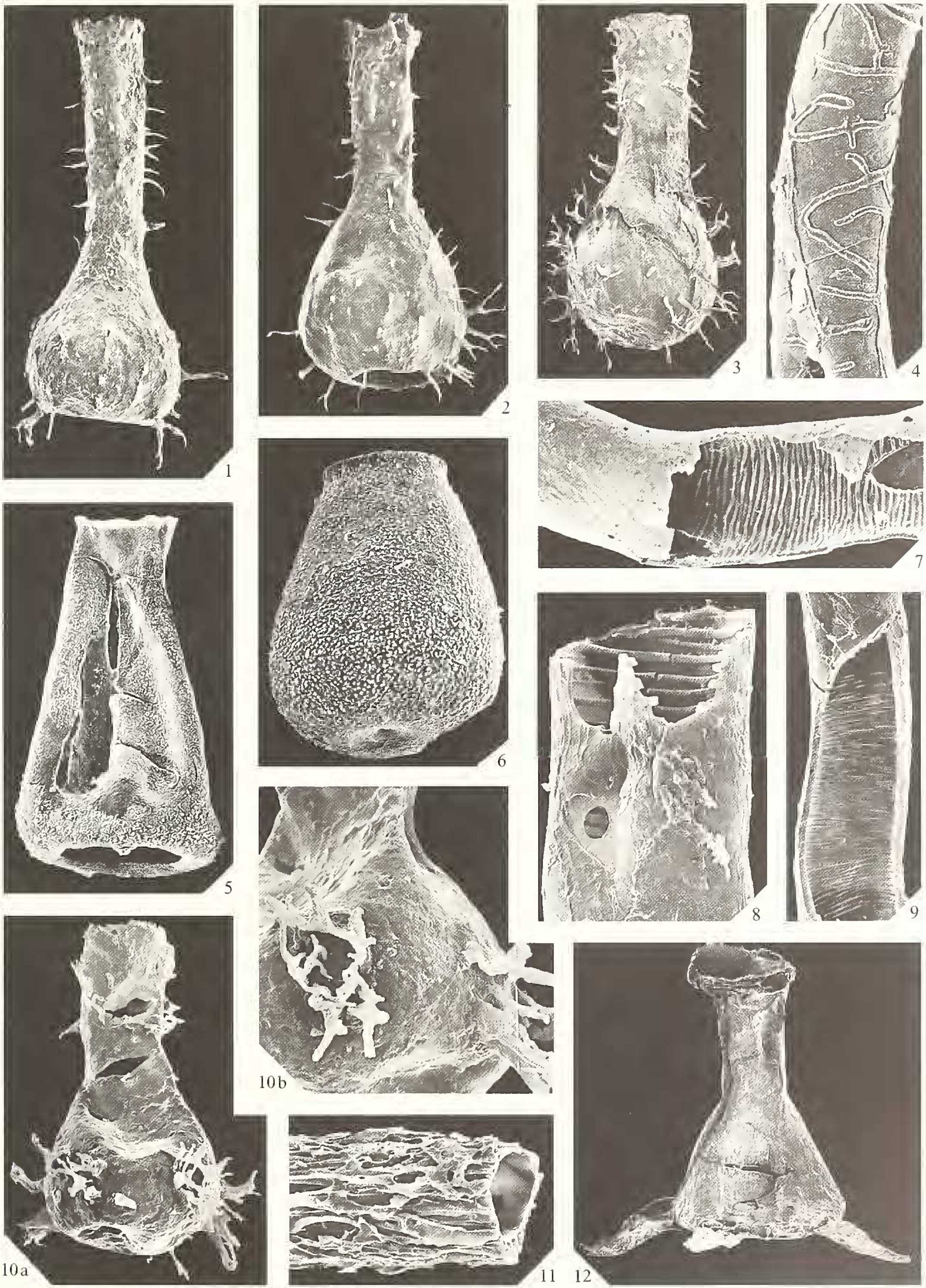
Fig. 6. *Eisenackitina bohemica* (Eisenack, 1934); P. 19, IGR 58721, (R. 43); ×250; note the slightly depressed anteapertural scar.

Figs 7–9. *Porcatitubulus*? sp. Burgess and Edwards, 1991. Organic 'tubes' showing a smooth outer surface and an annulate inner surface. 7, P. 32, IGR 58745, (O. 36); base of the Ivane Group; ×700. 8, P. 13, IGR 58710, (Q. 38/3); note the perforation of the tube wall of this specimen; lower part of the Tajna Formation; ×750. 9, P. 19, IGR 58721, (S. 41/2); top of the Tajna Formation; ×500.

Fig. 10a–b. *Ancyrochitina* sp. nov. A; P. 19, IGR 58721, (R. 39/4). a, specimen in lateral view; ×400. b, detail of the very diagnostic processes of this new species; ×750.

Fig. 11. Organic 'tube' with large, irregular, longitudinal ridges on its outer surface; P. 13, IGR 58721, (M. 40); lower part of the Tajna Formation; ×500.

Fig. 12. *Ancyrochitina* cf. *lemniscata* Wrona, 1980; P. 21, IGR 58725, (R. 38/1); note the very wide processes; ×250.



PARIS and GRAHN, Podolian chitinozoans and organic tubes

Dzwinogorod Formation in the Vokovtsy section (= section 64 in Nikiforova and Predtechenskij 1968). The assemblage extends up to sample P. 14 but *U. urna* ranges at least into the lowest quarter of the Tajna Formation as the species is still present in sample P. 16 (= bed 12 in section 64 of Nikiforova and Predtechenskij 1968). The distribution of *U. urna* is discontinuous in the lower part of the Tajna Formation. It is worth noting the occurrence of a few *Margachitina elegans* in sample P. 10. This species is well-known from the middle part of the Přídolí in northern Gondwana regions (Boumendjel 1987; Verniers *et al.* 1995). Some *Fungochitina* forms, including typical *Fungochitina kosovensis*, are also recorded in sample P. 10, which is dominated by *Calpichitina* sp. 1 (85 per cent. of the population).

Assemblage 3. This begins in the lower part of the Tajna Formation with the first occurrence of *Calpichitina velata* in sample P. 14. This species extends over about 50 m, i.e. almost all of the Tajna Formation. Its last record is in sample P. 18, which was collected a few metres below the Tajna–Mitkov boundary. Consequently, *C. velata* coexisted with both *U. urna* and with *Calpichitina annulata*. Until now, this latter species has only been recorded in the highest Přídolí beds of the Klonk section (Lochkovian GSSP) in Bohemia (Paris 1981; Paris *et al.* 1981). The highest specimens of *C. velata* coexisted with the first specimens of *Pterochitina megavelata* and *Margachitina catenaria*, two taxa well represented in the succeeding chitinozoan assemblage.

Assemblage 4. This assemblage begins at the appearance of *Eisenackitina bohemica* in sample P. 19 i.e. 0·25 m below the top of the Tajna Formation (upper part of bed 5 of Chudkovtsy section in Nikiforova and Predtechenskij 1968). *E. bohemica* is represented by only a few individuals in sample P. 19, but this important species dominates the chitinozoan assemblages higher up in the Mitkov Formation (e.g. 48 per cent. in sample P. 23 and 54 per cent. in sample P. 24). The greatest chitinozoan diversity is in the lower part of the Mitkov Formation where *P. megavelata* and *M. catenaria* are also well represented (respectively 26 per cent. and 32 per cent. of the chitinozoans recorded in P. 22). Other species seem to have a more restricted distribution e.g. *Ancyrochitina* sp. nov. A (sample P. 19) and *Ramochitina longispina* (sample P. 21).

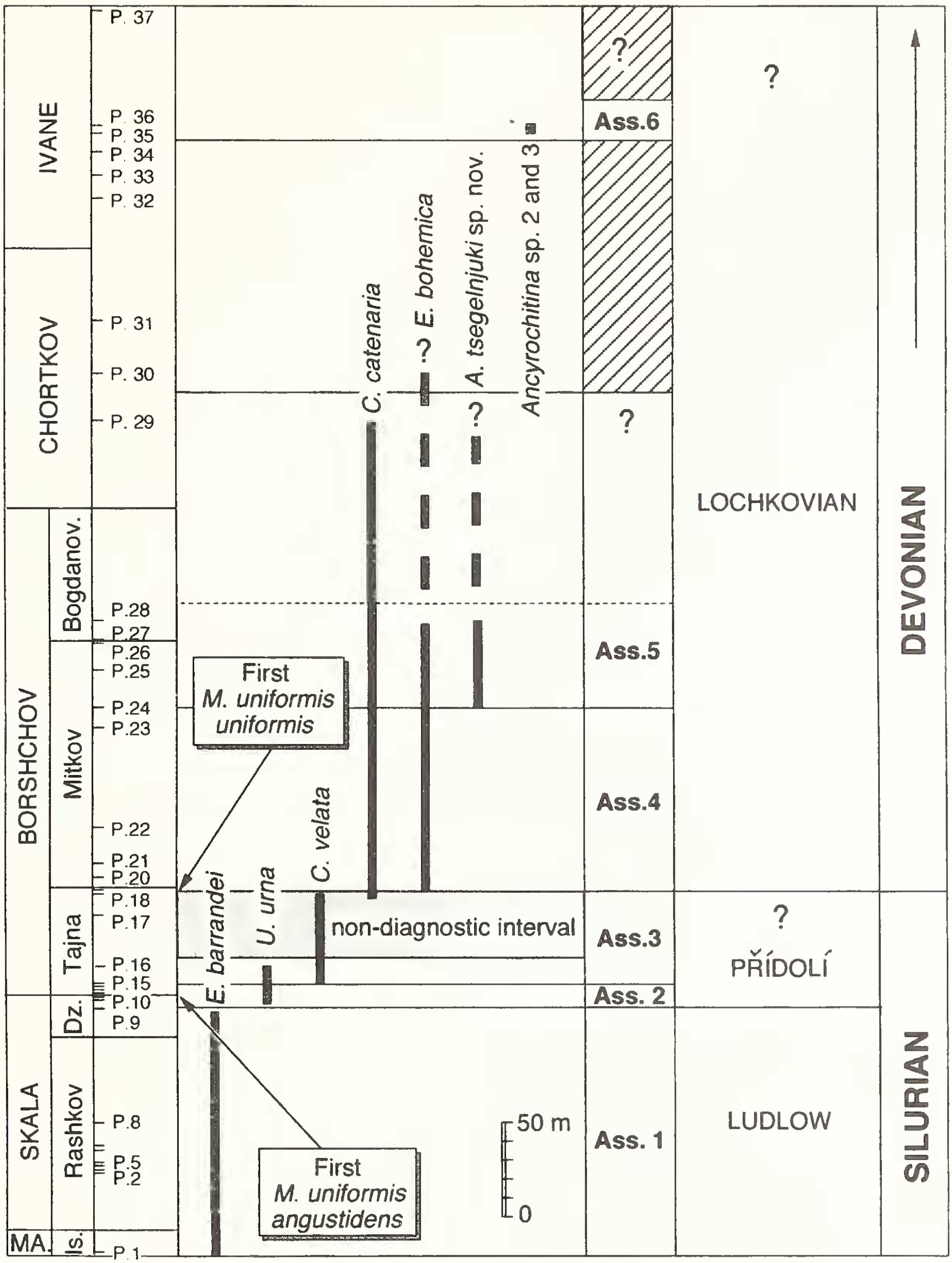
Assemblage 5. This corresponds to the total range of *Angochitina tsegelnjuki* sp. nov. from sample P. 24 to sample P. 28, and possibly up to P. 29, depending on the taxonomic status of a closely related form tentatively called here *A. tsegelnjuki* sp. nov.? This assemblage, therefore, characterizes the upper part of the Mitkov Formation, the lower part of the Bogdanovka Formation and possibly extends into the lower part of the Chortkov Group. The index species coexisted with the last representatives of *Margachitina catenaria* and *E. bohemica*. *E. elongata*, a stratigraphically more restricted taxon, is abundant in sample P. 27, at the base of the Bogdanovka Formation.

Assemblage 6. This assemblage is limited to samples P. 35 and P. 36 in the middle part of the Ivane Group. It is characterized by the occurrence of two distinctive forms: *Ancyrochitina* sp. 2 (Pl. 4, figs 3, 6, 9) and *Ancyrochitina* sp. 3 (Pl. 4, figs 1–2). A poorly preserved *Eisenackitina* form might belong to *E. bohemica*. The chitinozoans recovered from the upper part of the Bogdanovka Formation and from the lower part of the Ivane Group are too sparse and too poorly preserved to document convincingly any biozonation.

Chronostratigraphical assignment

Most of the index taxa selected here are regarded as good chronostratigraphical markers as their respective ranges are well constrained with respect to the Upper Silurian and Lower Devonian GSSP (Paris *et al.* 1981; Chlupáč *et al.* 1985; Kříž *et al.* 1986; Verniers *et al.* 1995; Paris 1996).

In Bohemia, *E. barrandei*, the index taxon of our Assemblage 1 in Podolia, is a typical Late Ludlow chitinozoan species (Paris and Kříž 1984). In the Prague basin, it is abundant in all sections exposing the Ludlow–Přídolí boundary (Kříž *et al.* 1986). It usually disappears at the top of the Ludlow, but, in some localities (e.g. Požári section, where the GSSP of the Přídolí is defined), *E. barrandei* extends a few hundred millimetres above the base of the Přídolí, i.e. above the first occurrence of *Monograptus parultimus* (see Kříž *et al.* 1986, fig. 7). In Podolia, this Assemblage 1, ranging from the Isakovtsy Formation to the upper two-thirds of the Dzwinogorod Formation, suggests that the Ludlow–Přídolí boundary is situated within the Dzwinogorod Formation, in all likelihood in its middle part. This age assignment is supported by the first occurrence of *U. urna* at the top of the Dzwinogorod Formation; in Bohemia, this world-wide chitinozoan index species for the Přídolí (Verniers *et al.* 1995) appears a few tens of millimetres above the first *M. parultimus* (Kříž *et al.* 1986). This chronostratigraphical assignment contradicts earlier stratigraphical conclusions,



TEXT-FIG. 3. Range of selected chitinozoan taxa and chronostratigraphical assignment based on chitinozoan evidence. Lithological units and thicknesses from Nikiforova and Predtechenskij (1968) and Koren' *et al.* (1989). (Hatching: barren interval. Abbreviations: Ass. = assemblage; MA. = Malinovtsy; Is. = Isakovtsy; Dz. = Dzwinogorod; Bogdanov. = Bogdanovka).

based on the local range of the conodonts *Ozarkodina remscheidensis eosteinhornensis* and *O. crispa* which placed the Ludlow–Přídolí boundary in the lower part of the underlying Rashkov Formation (Abushik *et al.* 1985). However, it should be stressed that in Bohemia *O. remscheidensis eosteinhornensis* and *O. crispa* occur within strata situated several metres below the base of the Přídolí (Kříž *et al.* 1986). Therefore, in our opinion, the occurrence of these two conodonts in the Podolian sections is not sufficient to locate precisely the Ludlow–Přídolí boundary. Ostracodes are of limited use because almost none of the Podolian taxa is reported from the Ludlow and Přídolí in Bohemia (Kříž *et al.* 1986). A bed-by-bed study of the chitinozoans from the highest ten metres of the Dzwinogorod Formation in the Volkovtsy section, would certainly pin-point more accurately the location of the Ludlow–Přídolí boundary in Podolia.

Based on chitinozoan data, especially on the total range of *U. urna*, the Přídolí appears to extend at least 15 m into the lower part of the Tajna Formation (Text-fig. 3) and possibly higher. There is an interval of 20 m which was not investigated within the 40 m thick sequence separating the last recorded *U. urna* from the appearance of *E. bohemica*, a diagnostic chitinozoan species for the Lochkovian (Paris 1981).

The chronostratigraphical conclusion concerning the Přídolí–Lochkovian boundary i.e. the Silurian–Devonian boundary, based on chitinozoan evidence, is again in disagreement with the age assignments proposed by previous workers. In particular, the chitinozoan evidence is in conflict with the conclusion of graptolite experts who have drawn the Silurian–Devonian boundary at the base of the Tajna Formation because *Monograptus uniformis angustidens* has its first occurrence in the basal bed of this unit (Koren' 1968). However, by definition, the base of the Devonian, and therefore of the Lochkovian, coincides with the first occurrence of *Monograptus uniformis uniformis* (McLaren 1977; Holland 1985), a closely related subspecies which has its first appearance much higher in the Podolian succession, i.e. three metres below the base of the Mitkov Formation in the Chudkovtsy section (Nikiforova and Predtechenskij 1968). In Bohemia, these two graptolite subspecies appear together in bed 20 of the Klonk section (GSSP of the base of the Devonian). Moreover, in Klonk, *Calpichitina annulata* is restricted to beds 18–20, i.e. very close to the first occurrence of *M. u. angustidens* in bed 20. A similar situation is noted in Podolia where *C. annulata* is only recorded in sample P.11, just below the first report of *M. u. angustidens* in the Chudkovtsy section (Nikiforova and Predtechenskij 1968). On the other hand, in both localities, *E. bohemica* has its first occurrence a very short distance above the appearance of *M. u. uniformis*. However, there is a major difference between these two localities: in the Chudkovtsy section a 54 m thick sequence separated the first occurrence of each graptolite subspecies, whereas in Klonk they occur in the same bed. This could be explained either by a more complete sedimentological record in Podolia or by

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EXPLANATION OF PLATE 3

Early Lochkovian chitinozoans from the Mitkov Formation of Podolia, Ukraine.

Figs 1–2. *Margachitina catenaria* Obut, 1973. 1, P.22, IGR 58728, (K.37/4); lateral view of a chain of four vesicles; ×300. 2, P.25, IGR 58733, (L.38/4); note the thick peduncle and the horizontal ribs on these specimens; ×300.

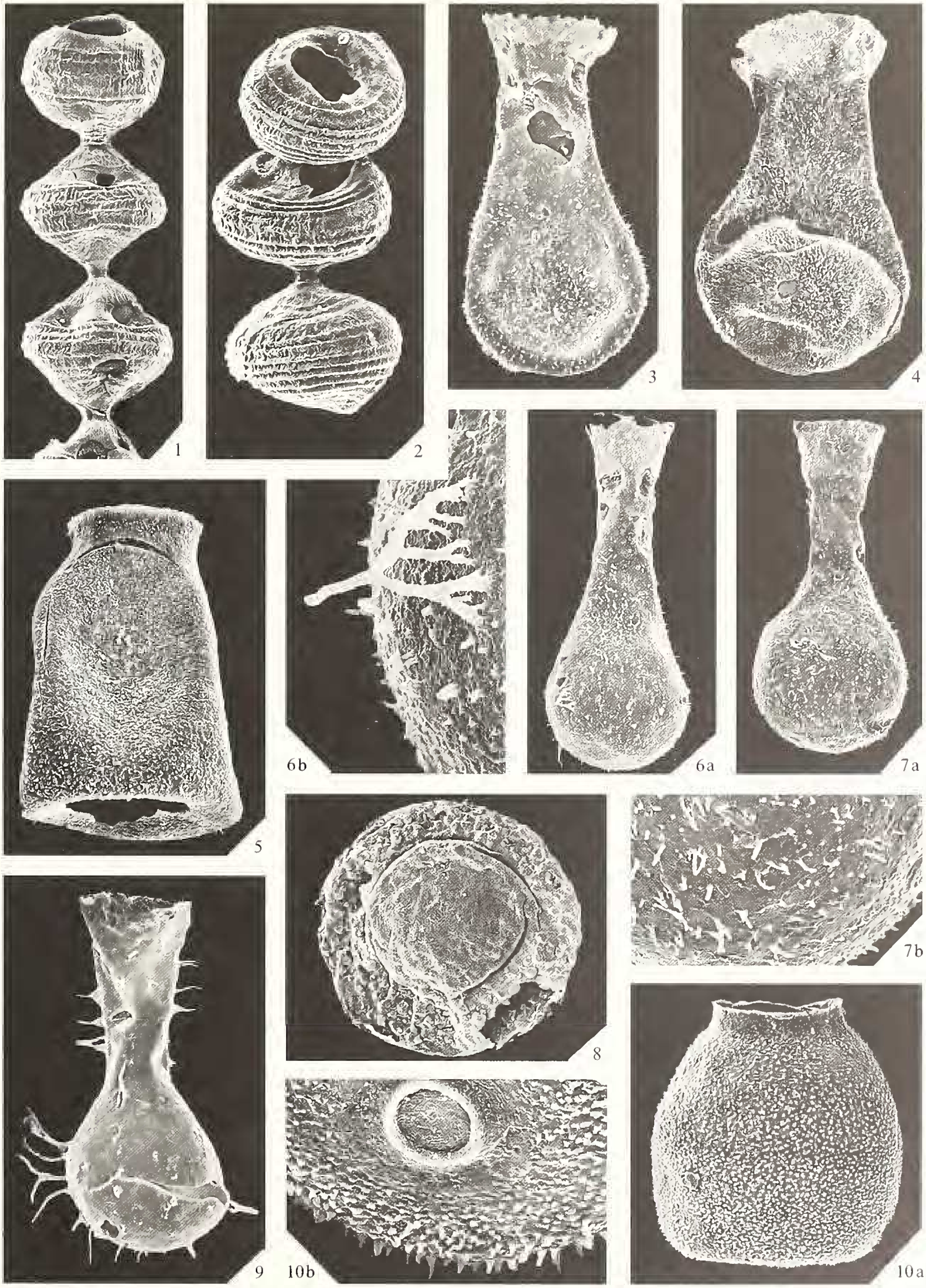
Figs 3–4, 6a–b, 7a–b. *Angochitina tsegelnjuki* sp. nov.; P.25, IGR 58733. 3, (N.42/1); lateral view of flattened paratype; ×300. 4, (L.40/3); lateral view of flattened paratype with a densely distributed spiny ornamentation; ×300. 6, (O.41), holotype. a, lateral view; ×300, b, detail of a multirooted spine; ×2000. 7, (M.39/1); atypical paratype with a fairly rounded chamber. a, ×300. b, detail of the spiny ornamentation; ×1000.

Fig. 5. *Eisenackitina invenusta* Wrona, 1980; P.24, IGR 58731, (P.39); ×350.

Fig. 8. *Pterochitina megavelata* (*nomen nudum*, *in* Boumendjel 1987); P.22, IGR 58728, (L.36/1); anteapertural view; ×300.

Fig. 9. *Ramochitina ramosus* (Paris, 1976); P.25, IGR 58733, (P.41/1); ×300.

Fig. 10a–b. *Eisenackitina bohemica* (Eisenack, 1934), P.22, IGR 58728. a, (Q.38/1); lateral view of a stubby specimen; ×250. b, detail of the mucron and of the spiny ornamentation on a tilted vesicle; ×750.



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the diachronous occurrence of some chitinozoan and graptolite species. If one adopts the first hypothesis, bed 20 in the Klonk section would represent a condensed or a disturbed deposit. In the second hypothesis, both *M. u. uniformis* and *E. bohemica* appeared later in Podolia whereas *U. urna* survived longer there than in Bohemia. Another alternative explanation may be that *M. u. angustidens* appeared earlier in Podolia than in Bohemia. We favour the sedimentological explanation because an obvious change in lithology, with a local erosional pattern, can be observed at precisely the Silurian–Devonian boundary in bed 20 of the Klonk section (see fig. 3 in Hladil 1991). Moreover, a similar biostratigraphical discrepancy is observed in Poland (Wrona 1980).

Assemblage 3, containing *Calpichitina velata*, is of more limited use for a high resolution age assignment as this taxon is also recorded in the uppermost Přídolí–lowermost Lochkovian beds of the Karlstejn section in Bohemia (= chitinozoan indet. n. gen.? n. sp. in Paris *et al.* 1981) and in the Bostovian–Lower Ciepielovian (= Lochkovian) of well Strzelce IG.2 in Poland (Wrona 1980). The species is also reported in the Lochkovian of Artois, northern France (Paris 1986) and in the Lochkovian and lower Pragian of Australia (Winchester-Seeto 1993).

Assemblage 4, corresponding to the lower part of the total range of *E. bohemica* and of *M. catenaria*, is typically of early Lochkovian age. Based on the known range of *E. bohemica* (Paris 1981, 1995; Chlupáč *et al.* 1985), the topmost Tajna Formation, the whole Mitkov Formation and at least the lower part of the Bogdanovka Formation are of Lochkovian age.

Assemblage 5, despite the fact that it corresponds to the total range of a new chitinozoan species i.e. *Angochitina tsegelnjuki*, is dated by the upper half of the *E. bohemica* total range biozone and also by the occurrence of *E. elongata*, a taxon already recorded in the upper Lochkovian in Bohemia (e.g. bed No. 5 of the Trebotov section; bed 10/11 in the Kosor section; Paris *in* Chlupáč *et al.* 1985). The Late Silurian–Early Devonian *Margachitina* species usually display an evolutionary trend of progressive thinning of the peduncle (Paris 1981). This is illustrated by the lineage *M. crassipes* (late Přídolí), *M. catenaria* (early Lochkovian) and *M. tenuipes* (late Lochkovian–early Pragian). The youngest individuals recorded in Podolia (sample P.29, from the lower part of the Chortkov Group) still belong to *M. catenaria*. Therefore, it is concluded that the base of the Chortkov Group is still Lochkovian.

In assemblage 6, from the Ivane Group, the two dominant forms *Ancyrochitina* sp. 2 and *Ancyrochitina* sp. 3 are not, as yet, useful for chronostratigraphical purposes. However, the

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EXPLANATION OF PLATE 4

Lochkovian chitinozoans from the Bogdanovka Formation (figs 5a–b, 8a–b), and from the Chortkov (figs 10a–b) and Ivane groups (figs 1–4, 6–7, 9), Podolia, Ukraine.

Figs 1–2. *Ancyrochitina* sp. 3; P.36, IGR 58752. 1, (M.40/2); damaged specimen with short spines covering the entire vesicle; ×400. 2, (M.39/3); detail of the spiny wall of another specimen; ×1000.

Fig. 3. *Ancyrochitina* sp. 2; P.35, IGR 58750, (N.36/3); specimen with collapsed flanks; ×400.

Fig. 4. *Ramochitina* sp. indet.; P.33, IGR 58747, (R.39/3); ×400.

Fig. 5a–b. *Eisenackitina bohemica* (Eisenack, 1934); P.27, IGR 58738 (N.35/3). a, flattened specimen in lateral view; ×250. b, detail of the anteapertural scar, clearly without perforation; ×1000.

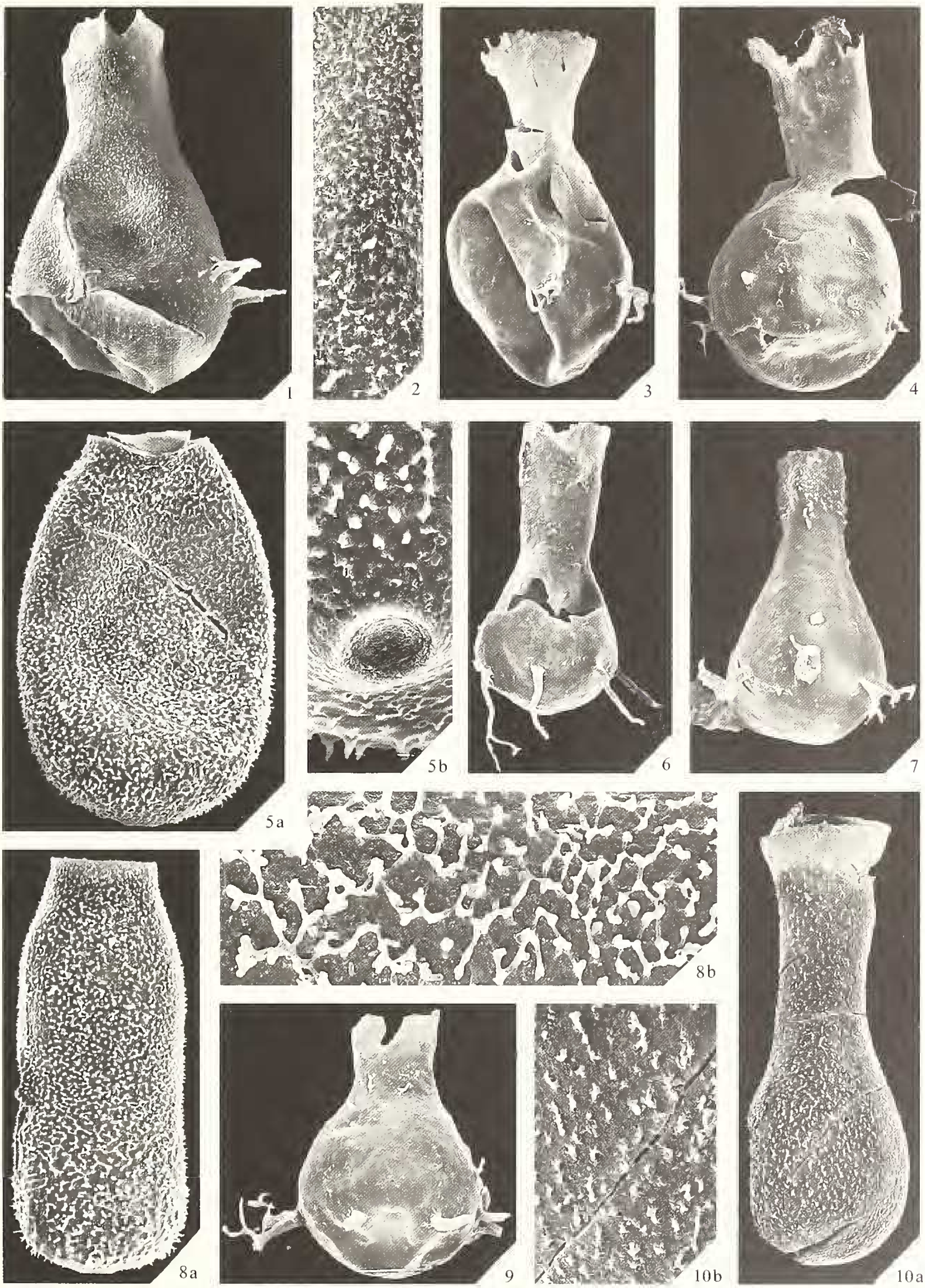
Fig. 6. *Ancyrochitina* sp. 2; P.35, IGR 58750, (P.33/1); note the granulose ornamentation of the neck; ×300.

Fig. 7. *Ancyrochitina* sp. indet.; P.35, IGR 58750, (P.33/1); note the granulose ornamentation of the neck; ×300.

Fig. 8a–b. *Eisenackitina bohemica* (Eisenack, 1934); P.27, IGR 58738, (P.35/2). a, very slender specimen with a silhouette recalling that of *E. elongata* Eisenack, 1972; ×250. b, detail of the peculiar ornamentation with ridges joining the spines; ×1000.

Fig. 9. *Ancyrochitina* sp. 2; P.35, IGR 58750, (Q.35/3); note the multibranched processes of this specimen which has a partly broken neck; ×400.

Fig. 10a–b. *Angochitina tsegelnjuki* sp. nov.?; P.29, IGR 58742, (M.41/4). a, large specimen in lateral view; ×300. b, detail of the short spiny ornamentation of the chamber; note the presence of some multirooted spines and a flaring collarette; ×1000.



PARIS and GRAHN, Podolian chitinozoans

occurrence of a very poorly preserved specimen of *Eisenackitina* in sample P.35 would suggest that the Ivane Group should still be Lochkovian. The nearshore environment which prevailed during the deposition of the Ivane sediments was too unfavourable for chitinozoan preservation to permit accurate biostratigraphical conclusions based only on chitinozoan evidence. However, based on the few miospore assemblages illustrated by Arkhangelskaya (1980), both the Chortkov and Ivane groups contain forms belonging to the lower and middle part of the *micrornatus-newportensis* spore Zone (Richardson *et al.* 1981, 1984).

Stratigraphical conclusions

The changes we propose in the present study for the position of some chronostratigraphical limits in the Upper Silurian–Lower Devonian sequences of Podolia are documented by direct correlation with the international stratotypes of Bohemia. These modifications in the local chronostratigraphy have important consequences for other groups reported from Podolian localities, such as pteraspids (Karatajute-Talimaa 1978; Blieck 1984) and spores (Arkhangelskaya 1980, Steemans 1989) as these fossils have been used frequently for indirect dating of non-marine strata (e.g. Richardson *et al.* 1981, 1984). So far, the Silurian–Devonian sequence of Podolia seems to provide one of the most complete records of upper Přídolí–lower Lochkovian deposits yielding chitinozoans as well as acritarchs and miospores. Therefore, this succession should be used for a high resolution biostratigraphical study, integrating detailed sedimentological investigation and a bed-by-bed record of palynomorph groups and other fossils of stratigraphical value. Such data should serve as a key for accurate correlation of marine and non-marine deposits close to the Silurian–Devonian boundary.

SYSTEMATIC PALAEONTOLOGY

Only one new species and one form kept in open nomenclature are described briefly here. The material is deposited in the 'collections de l'Institut de Géologie de Rennes' (IGR) under the numbers 58707 to 58755. England–Finder co-ordinates are used to locate the specimens on the palynological slides. The morphological terminology is that discussed by Paris (1981) with some modifications and additions. The following symbols are used: L (total length of the vesicle), l (length of the chamber), D (maximum diameter of the chamber), d (diameter of the neck), dcoll. (diameter of the collarette). The measurements were made on full relief specimens.

Order PROSOMATIFERA Eisenack, 1972
Family LAGENOCHITINIDAE Eisenack, 1931 emend Paris, 1981
Subfamily ANGOCHITININAE Paris, 1981
Genus ANGOCHITINA Eisenack, 1931

Type species. Angochitina echinata Eisenack, 1931.

Angochitina tsegelnjuki sp. nov.

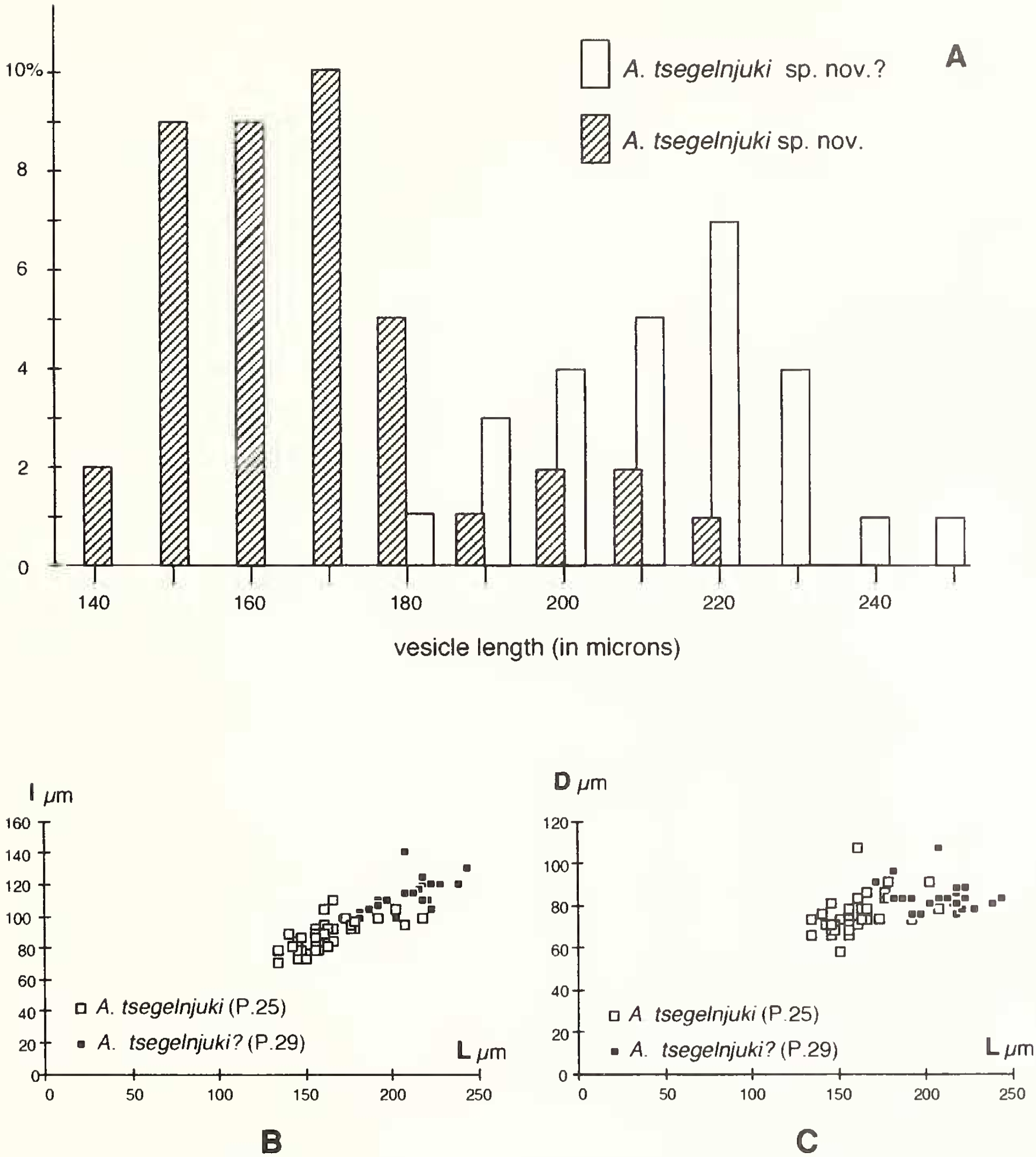
Plate 3, figures 3–4, 6a–b, 7a–b

Derivation of name. To honour Professor Tsegelnjuk (University of Kiev, Ukraine) for his work on Silurian chitinozoans from Podolia.

Holotype. IGR 58753 (O.41) (Pl. 3, fig. 6a); Upper Mitkov Formation, 15 m below its top, Lochkovian; Bogdanovka village, exposure in a creek on the left side of the Dnestr River.

Paratypes. IGR 58753 (N.42/1) (Pl. 3, fig. 3); IGR 58753 (L.40/3) (Pl. 3, fig. 4), IGR 58753 (M.39/1) (Pl. 3, fig. 7a).

Material. Over 200 specimens, both flattened and in full relief, recorded in samples P.24–P.28.



TEXT-FIG. 4. A, histogram of the variation of the vesicle length (L) in *Angochitina tsegelnjuki* sp. nov. (from sample P.25) and *A. tsegelnjuki* sp. nov.? (from sample P.30). B, variation of the length of the vesicle (L) with regard to the length of the chamber (l) for *A. tsegelnjuki* sp. nov. (open squares) and *A. tsegelnjuki* sp. nov.? (black squares). C, variation of the length of the vesicle (L) with regard to the diameter of the chamber (D) for *A. tsegelnjuki* sp. nov. (open squares) and *A. tsegelnjuki* sp. nov.? (black squares).

Diagnosis. An *Angochitina* species provided with an ovoid to pear-shaped chamber; neck shorter than the chamber and ending with a flaring membranous collarette; ornamentation of tiny spines densely distributed on the whole vesicle and of a few multirooted spines restricted to the chamber.

Description. This medium-sized new species (L = 163 µm; D = 75 µm) is characterized by an ovoid to pear-shaped chamber passing progressively to a fairly short neck flaring toward the aperture. This neck, including a widened membranous collarette, is shorter than the length of the chamber (L/l = 1.86). The flexure is usually poorly marked (Pl. 3, fig. 6a), especially when the vesicle is flattened (Pl. 3, figs 3–4). Tiny spines (length up to 15 μm when complete; diameter over 1 μm), usually simple or of lambda type (Pl. 3, fig. 7b), cover the entire vesicle, but fade away on the collarette and on the apex of the chamber (Pl. 3, figs 3–4). They may occur together with a few multirooted and better developed spines (Pl. 3, fig. 6b). This spiny ornamentation is fragile and usually only the proximal part is preserved. The aperture is straight to slightly denticulate (Pl. 3, fig. 3).

Dimensions (Text-fig. 4A–C). Thirty-five specimens in full relief from sample P.25 were measured (values in microns).

	L	l	D	d	dcoll.
Holotype	174	99	73	27	47
Mean	163	87	75	32	48
Range	218–135	109–70	91–57	49–23	67–34

Remarks. Angochitina crassispina pelosa Schweineberg, 1987, from the Los Arroyacas Formation (Přídolí of Spain), has a conspicuous flexure and a better developed neck than *Angochitina tsegelnjuki* sp. nov. In addition, the multirooted spines scattered within the ornamentation of the Spanish form are more robust than those of *A. tsegelnjuki* sp. nov. Our new species has also a silhouette different from that of *Angochitina hypenetes* Winchester-Seeto, 1993 from the Lochkovian of Australia.

In Podolia, higher up in the succession, in the lower part of the Chortkov group, sample P.29 yields a very closely related form which we tentatively call *A. tsegelnjuki* sp. nov.? This form differs only from the type material of our new species by its greater dimensions (see mean values below) and by the peculiar design of the proximal ends of its multirooted spines which are more or less parallel to the longitudinal axis of the vesicle (Pl. 4, fig. 10a–b).

Stratigraphical range. Angochitina tsegelnjuki sp. nov. ranges from the upper part of the Mitkov Formation to the lower part of the Bogdanovka Formation. These strata are Lochkovian as they yield *E. bohemica* (see discussion above).

Angochitina tsegelnjuki sp. nov.?

Plate 4, figure 10a–b

Material. 276 specimens, both flattened or in full relief, recorded in sample P.29.

Description. This *Angochitina* form has an ovoid chamber provided with a large widened membranous collarette. The length of the chamber is similar to that of the neck. The whole vesicle is covered by tiny multirooted spines (Pl. 4, fig. 10b) which are less developed on the chamber bottom and on the collarette (Pl. 4, fig. 10a). The bases of these spines are more-or-less parallel. However, they are not arranged in true crests.

Dimensions (Text-fig. 4A–C). Based on 20 specimens in full relief from sample P.29 (measurements in microns).

	L	l	D	d	dcoll.
Mean	209	113	84	40	60
Range	244–182	130–99	106–75	52–32	72–52

Remarks. The histogram of the vesicle length (L) clearly shows a bimodal distribution between *A. tsegelnjuki* sp. nov. from sample P.25 and *A. tsegelnjuki* sp. nov.? from sample P.29. This suggests the occurrence of two distinct populations. However, due to the lack of abundant individuals between samples P.25 and P.29, it is difficult to decide if these populations represent the two extremes of an evolutionary trend within a single species, or two separate species. For that reason, we use only a question-mark to distinguish the two forms.

Stratigraphical range. Angochitina tsegelnjuki sp. nov.? occurs mainly in sample P. 29 from the lower part of the Bogdanovka Formation, Lochkovian (see stratigraphical discussion above).

Sub family ANCYROCHITININAE Paris, 1981

Genus ANCYROCHITINA Eisenack, 1955

Type species. Conochitina ancyrea Eisenack, 1931.

Ancyrochitina sp. nov. A

Plate 2, figure 10a–b

Material. Two specimens from sample P. 19; topmost Tajna Formation.

Description. This small *Ancyrochitina* species is very distinctive because of the occurrence of five or six wide 'crested' processes which are distributed around the margin (Pl. 2, fig. 10a). These 'crested' processes seem to issue from large hollow processes which are open distally and end with a deeply indented membrane simulating a crown of branched straps (Pl. 2, fig. 10b).

This new species is kept in open nomenclature due to insufficient material. However, it seems to have stratigraphical potential as it is already known at a depth of 2040·30 m, in core 12 from well A1–61, Lochkovian of western Libya (Paris unpublished data).

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